The Effect of Fractional Replacement of Calcium with Lanthanum on the Characteristics of $HgBa_2Ca_{2-x}La_xCu_3O_{8+\delta}$ Compound

Fouad Waheed Ali[1*], Firas Kadhim Nsaif[1], Kassim Mahdi Wadi[2], Kareem A. Jasim[1], Auday H. Shaban[3]

Abstract

The current work involves the study of the substitution effect of calcium instead of lanthanum on the structural and electric characteristics at room of the $HgBa_2Ca_{2-1}La_xCu_3O_{8+\delta}$ compound with (x = 0, 0.2, 0.4, 0.6 and 0.8). The specimens were manufactured via solid status reaction process. The results of X - radiation deviation showed for all samples a tetragonal system, containing the highest proportion of the pure (Hg - 1223) stage with low percentages for the minor phases (Hg - 1212, 1201) and appearance of some impurities, and the highest phase rate for the specimen at (x = 0.4) which is equal to (84.69%) and characterized by absence of impurities. The results of the measurement of the lattice constants, (c. 1 / a) and the density of mass shows that a sample with (x = 0.2) has the highest value (c / a = 4.602) and highest value of crystal size (D = 84.7 nm). The four - sensor procedure was achieved to detection the transition temperature Tc and the results confirmed the metal behavior of all samples. There was a change in the critical temperature, which increased from (111 to 119) Kelvin when the concentration of lanthanum increased from zero to 0. 2 and became 114 K at x = 0. 4 and then decreased to (105 and 98) Kelvin at x = 0.6 and 0.8.

Key Words: Lattice Constants, Crystal Size, Tetragonal System, Structural and Electric Characteristics.

DOI Number: 10.14704/nq.2020.18.11.NQ20230 **NeuroQuantology 2020; 18(11):19-24**

Introduction

It is known that the materials in general are classified in terms of electrical conductivity to conductive materials, semiconductor materials and insulating materials, and that this classification is controlled by the structural nature of the material as well as the strength of the binding of electrons of atom with nucleus. The fourth type which had a significant impact in attracting the investigators specialized in physical of solid status is a superconductivity event and in the past it has invested in many domains which included scientific and procedural aspects. In order to keep abreast of evolutions that man is going through and saving time, overwork and expenditure on him, hyper conductive materials have emerged which are of excessive significance as a produce of nonstop investigation and find of new materials. Achieving a high critical temperature and increasing the data in science of materials is the aim of investigators into this kind of material which will develop its Scientific and technical implementations. Superconductivity is affected by the amplitude of heat, the critical value of both the magnetic field, density of current and temperature and they represent most of the physical characteristics of hyper conductive materials and differs from one substance to another.

Corresponding author: Fouad Waheed Ali
Address: [1*]Department of Physics - College of Education for Pure Sciences (Ibn Al Haitham), University of Baghdad, Baghdad, Iraq; [2]Al-Ma'amoun University College, Electrical Engineering Techniques Department, Iraq; [3]College of Science, University of Baghdad, Baghdad, Iraq.
Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
Received: 18 August 2020 **Accepted:** 10 October 2020

There is no resistance in all hyper conductive materials when the present magnetic field not overtaken its critical rate or there is no magnetic field and that means superconductivity is a thermo dynamic status and therefor has some characteristic that are broadly separately of microscopic specifics.

The finding of the elevated-temperature hyper conducting ceramic compounds caused a somewhat massive revolution in the world through its wide implementations in the electrical and electronic field. The mechanisms by which superconductivity happens can be understood by discussion the replacement or increment processes of elements, especially in copper compounds [1, 3].

Among the most important superconducting compounds are the mercury-based compounds with a chemical composition (Hg-Ba-Ca-Cu-O) of elevated-temperature hyper conducting which are represented by intensive research activity. Especially, the $HgBa_2Ca_2Cu_3O_{8+\delta}$ stage gets attention due to its electrical characteristics, elevated - current and differentiation in the properties that lies between the Y and Bi bearing. It is probable that the effluent fixation process and the effective microscopic structure showing good tissue texture will appear [4]. It has been reported that Hg-1223 phase contain zero resistance temperature (130-135) K [5, 6]. However, despite these characteristics its usage hasn't been as predominant as other superconducting compound. It is caused by the great difficulty in production of HTSC phases bearing Hg inclusive (Hg - 1223) due to its severe sensitivity to pollution from moisture and CO_2. The (Hg -1223) specimens are famous to rapidly damage after production. After that, great hard work have lately been prepared to increase the stability of the (Hg - 1223) stages. It is now known that partial substitution of HgOd in the hypoxic HgOd level using Tl or Pb can instill structure of (Hg - 1223) then increase T_c of prepared samples [7, 8]. As well as, the fractional replacement of mercury by Re or Sb significantly enhances the chemical stabilization and flow stabilization characteristics of (Hg - 1223) [9, 10].

Despite numerous research on substitution and addition, no fixed procedures and appliances have been discovered for the addition and replacement for the elements in this kind of substance complementing our scientific project of studying the replacement of chemical elements of superconducting compounds. In this paper we will address preparation and study effect of the fractional replacement of calcium by lanthanum on the some physical Characteristics for $HgBa_2Ca_{2-x}La_xCu_3O_{8+\delta}$ compound. Hence the motivation to enrich the searches through our modest effort, hoping to achieve the goal.

Experimental

High purity element oxides powders of HgO (purity > 99.8%), BaO (purity > 99.9%), CaO (purity > 99.9%), La_2O_3 (purity > 99.9%) and CuO (purity > 99.9%) were mixed in agate slurry according to the chemical formula:

$2HgO+4BaO+2CaO_{2-X}+xLa_2O_3+6CuO \rightarrow 2HgBa_2Ca_{2-X}La_xCu_3O_{8+\delta}$ (x = 0, 0.2, 0.4, 0.6 and 0.8).

The powder mixture was placed in a cylindrical container which was 1.5 cm in diameter and 10 cm high and pressed at 7 tons / cm^2 to obtain samples with a diameter of 1.5 cm and a depth of 0.3 cm, and the porosity of the nodes was about 50%. The reactive agreement in the quartz crucible was loaded into the graphite substrate and placed in a programmed furnace. The furnace temperature was raised to 850 degrees for 30 hours at a rate of five degrees per second, after that the furnace temperature fell to the temperature of room at the same rate of rise. Property of dependence of the resistance on temperature for these specimens was achieved by the four - sensor procedure to detection the superconducting status and transition temperature Tc are described elsewhere [11, 12]. The construction of the manufactured specimens was acquired using X - radiation deviation and a laptop software based on the Cohen last Squair process [12] was applied to determine the lattice constants.

Consequences and Argumentation

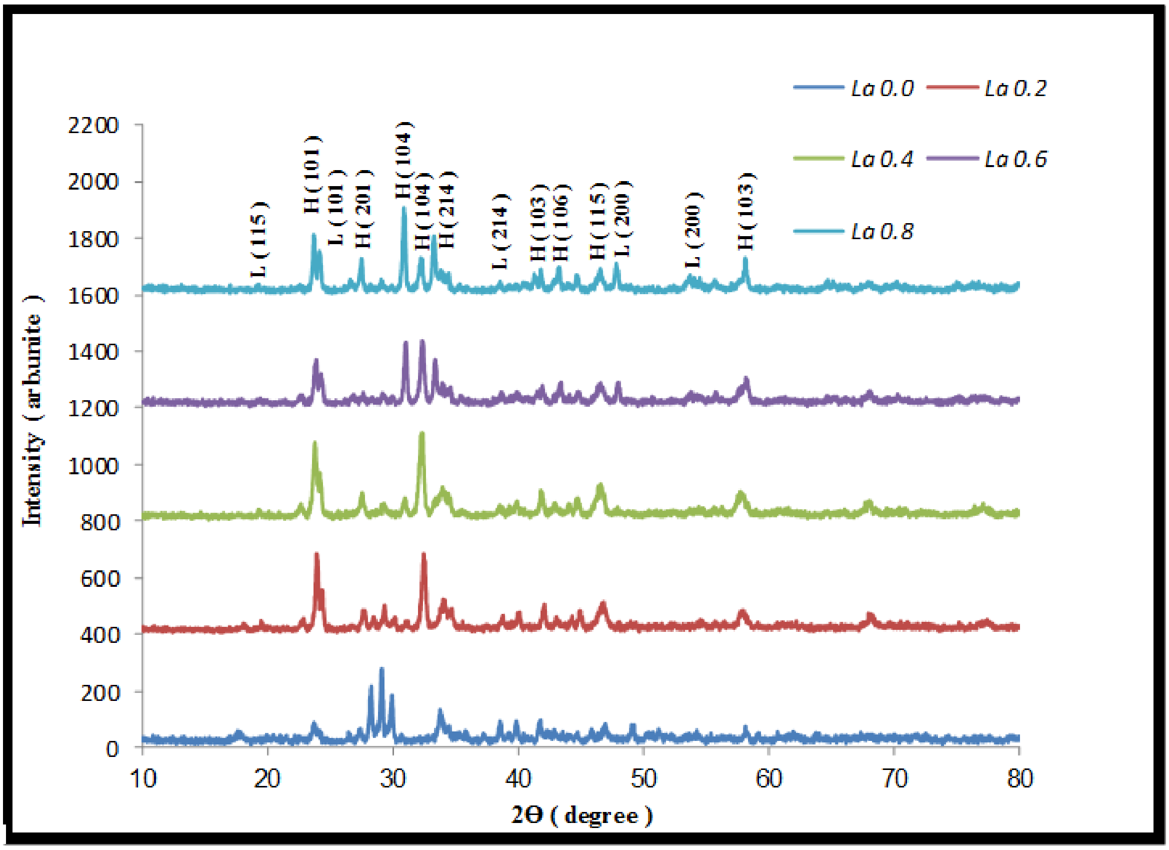
X - Radiation Deviation

The X - radiation deviation shapes for $HgBa_2Ca_{2-X}La_xCu_3O_{8+\delta}$ superconducting compound at (x = 0, 0.2, 0.4, 0.6 and 0.8) are presented in scheme 1. Our specimens generally include the primary (Hg - 1223) stage (H stage), secondary (Hg - 1212) stage (L stage) and low quantity of a secondary not defined, this is illustrated by sites and sharpness of the deviation summits. We note increase in H - stage besides decrease in L - stage by rising lanthanum concentration from 0 to 0.2 and decreasing in H-phase when increase the lanthanum above 0.2 value, these results are consistent with our results in research [13].

The lattice parameters for the $HgBa_2Ca_{2-x}La_xCu_3O_{8+\delta}$ compound at (x = 0, 0.2, 0.4, 0.6 and 0.8) were calculated using values (d) and miller indices (hkl) obtained from the X - ray diffraction pattern reflections, then the lattice constants and (c. 1/a) observed by use the Cohen last squair program. The parameters found from the program are shown in the table. The values of lattice constants shown that the construction of all the specimens have a tetragonal structure. The lattice constant (c-axis) and (c. 1/a) raised besides raising of La concentration confronted with that which does not contains La. This consequence can be illustrated by the fact that calcium ion radius (Ca^{+2} = 2.23 A°) smaller than that lanthanum ion radius (La^{+3} = 2.74 A°) [14, 15]. Crystal size (D) of all samples are calculated by using Scherrer equation, it was shown that in the lanthanum concentration produced changing in crystal size (D) as shown in table 1.

Table 1. Data of critical temperature $T_{c\,(offset)}$, lattice constants, (c / a) and crystal size (D) for $HgBa_2Ca_{2-x}La_xCu_3O_{8+\delta}$ compound at (x = 0, 0.2, 0.4, 0.6 and 0.8).

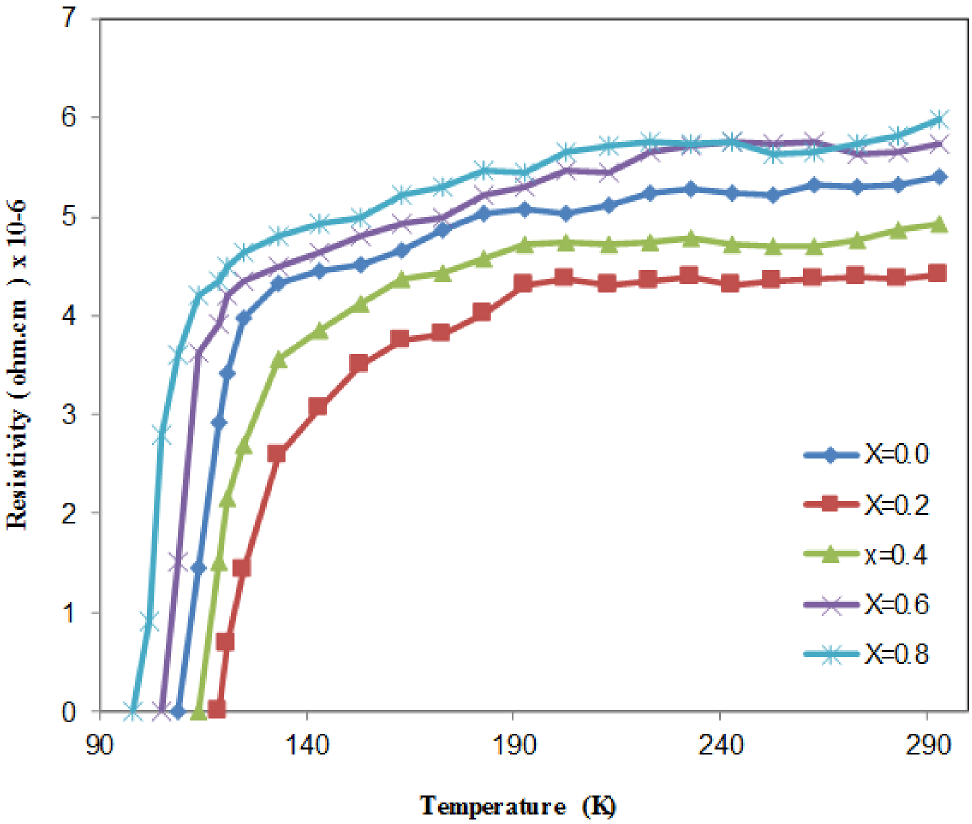
X	$T_{c\,(offset)}$ (K)	a (A⁰)	b (A⁰)	c (A⁰)	c / a	D (nm)
0	111	3.51	3.51	15.8	4.502	83.4
0.2	119	3.44	3.44	15.83	4.602	84.7
0.4	114	3.47	3.47	15.71	4.527	83.4
0.6	105	3.49	3.49	15.65	4.485	81.8
0.8	98	3.42	3.42	15.69	4.588	82.1



Scheme 1. XRD patterns for $HgBa_2Ca_{2-x}La_xCu_3O_{8+\delta}$ compound for different La concentration.

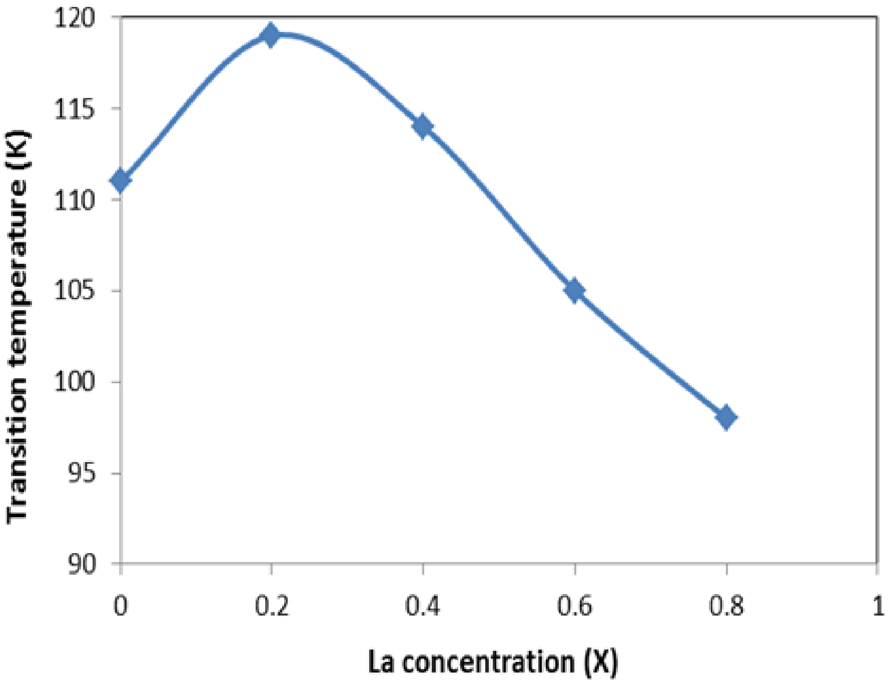
DC Electrical Resistivity

Scheme 2 shows the temperature dependent D.C Electrical Resistivity for $HgBa_2Ca_{2-x}La_xCu_3O_{8+\delta}$ compound at (x = 0, 0.2, 0.4, 0.6 and 0.8). It is noted that critical temperature T_c is influenced consequence of lanthanum raise. The shape curves below exhibits two different regions. The first part of the high temperature corresponds to the normal state which shows metallic behavior (above onset and offset critical temperature $2T_c$). Where it was observed that the natural resistance is linear and has a slight decrease from the room temperature to a certain temperature higher than the critical degree and the other part is the region that is characterized by the contribution of the fluctuation of the cooper pairs to the conductivity when approaching T_c. This is mainly due to the increased rate of pair formation to lower the temperature. From the ρ-T plot it is noted that the metallicity of the specimens changes with increase the La concentration. After that, the electrical resistance decreases rapidly, until it becomes zero in all samples. However, the critical temperature rises from 111 K for the non-La sample to 119 K, when the percentage of lanthanum increases to 0.2, then it decreases to (114, 105 and 98) K when increasing the ratio 0.4, 0.6 and 0.8 respectively. This change occurred because of the move away from the optimum value of lanthanum, whether it is a decrease or an increase [6]. From the ρ-T plot it is noted that the metallicity of the specimens changes with raise the La concentration. The summit expansion is happening consequence to raise of La which is influences the intergranular softy join between particles.



Scheme 2. Resistance variation as a function of temperature for $HgBa_2Ca_{2-x}La_xCu_3O_{8+\delta}$ compound at (x = 0, 0.2, 0.4, 0.6 and 0.8).

Scheme 3 shows the temperature derivative of La concentration samples. Several of critical temperatures are noted from the various composition through incorporation for nano-particles of La as listed in the table. The temperature derivative of curve shows an increasing trend with increasing 0.2 of La and then decreasing when Lanthanum concentration arise to 0.2.



Scheme 3. Variation of transition temperature against concentration of La for $HgBa_2Ca_{2-x}La_xCu_3O_{8+\delta}$ compound at (x = 0, 0.2, 0.4, 0.6 and 0.8).

Conclusions

Five $HgBa_2Ca_{2-x}La_xCu_3O_{8+\delta}$ compound with (x = 0, 0.2, 0.4, 0.6 and 0.8) specimens were manufactured via solid status reaction process. It is observed when the La concentration increases up to 0.2, the content of (Hg - 1223) and (H - stage) are increasing, after that all phases change at the concentration greater than 0.2 and the content of (Hg - 1223) is decreasing. X - Radiation deviation investigations shows a tetragonal construction for all specimens besides an existing quaternary structure. Increasing the concentration of La leads to a change in both the lattice constants, (c / a) and crystal size (D).

The best concentration of La was at 0.2 which had the greatest critical temperature (119 K) and then it decreased to 98 K at x = 0.8.

References

Jasim KA, Makki SA, Abud Almohsin A. Comparison Study of Transition Temperature between the Superconducting Compounds Tl0. 9 Pb0. 1 Ba2Ca2Cu3O9-δ, Tl0. 9Sb0. 1Ba2Ca2Cu3O9-δ and Tl0. 9Cr0. 1Ba2Ca2Cu3O9-δ. *Physics Procedia* 2014; 55: 336-341.

Jasim KA. The Effect of Cadmium Substitution on the Superconducting Properties of Tl 1− x Cd x Ba 2 Ca 2 Cu 3 O 9− δ Compound. *Journal of superconductivity and novel magnetism* 2013; 26(3): 549-552.

Ali AH, Ali AKD, Jasim KA. Influence of simultaneous doping of Ag on the critical temperature and the lattice constants of Tl1. 6 Hg0. 4-xAgx Ba2 Ca2Cu3O10+ δ superconductors. *In AIP Conference Proceedings, AIP Publishing LLC* 2019; 2123 (1): 020079.

Giri R, Singh HK, Tiwari RS, Srivastava ON. Effect of cationic size in Hg (Tl/Bi) Ba 2 Ca 2 Cu 3 O 8+ δ on superconducting and microstructural characteristics. *Bulletin of Materials Science* 2001; 24(5): 523-528.

Fujii H, Kumakura H, Togano K. Properties of (Hg, X)-1223 superconductors synthesized without using a glove box. *IEEE Transactions on Applied Superconductivity* 1999; 9(2): 1688 – 1691. http://doi.org/10.1109/77.784777

Putilin SN, Antipov EV, Chmaissem O, Marezio M. Superconductivity at 94 K in HgBa2Cu04+ δ. *Nature* 1993; 362(6417): 226-228.

Jasim KA. Comparison Study of Tc Between the Superconducting Compounds Bi_{2-x} (Hg, $Pb)_xSr_{2-y}$ $Ba_yCa_2Cu_3O_{10+\delta}$ and Hg1-xPbxSr2-y BayCa2Cu3O8+ δ (Doctoral dissertation, Ph. D Thesis, University of Baghdad, College of Science, Physics Dep. Iraq) 2005.

Kishio K, Shimoyama J, Yoshikawa A, Kitazawa K, Chmaissem O, Jorgensen JD. Chemical doping and improved flux pinning in Hg-based superconductors. *Journal of Low Temperature Physics* 1996; 105(5-6): 1359-1365.

Li JQ, Lam CC, Peacock GB, Hyatt NC, Gameson I, Edwards PP, Abell JS. (Hg, Sb) Ba2Ca2Cu3O8+ thick films on YSZ substrates. *Superconductor Science and Technology* 2000; 13(2): 169–172.

Jasim KA. Influence of Simultaneous Doping of Tl on the Transition Temperature Tc and the Lattice Parameters of HgBa2Ca2Cu3O8+δ Superconductors. *Ibn Al-Haitham Journal of Pure and Applied Science* 2009; 22(3).

Jasim KA, ALwan TJ, Mahdi KH, Mansour HL. The effect of neutron irradiation on the properties of Tl_ {0.6} Pb_ {0.3} Cd_ {0.1} Ba_2Ca_2Cu_ {3} O_ {9-delta} superconductors. *Turkish Journal of Physics* 2013; 37(2): 237-241.

Manivannan V, Gopalarishnan J, Rao CNR. Synthesis of Cuprates of Perovskite Structure in the Ba-Pb-Cu-O, Ba-Bi-Cu-O, and Ba-Pb-Tl-Cu-O Systems: Possible High Tc Superconductivity in a Perovskite-like Phase in the Ba-Pb-Tl-Cu-O System. *Journal of Sold state Chemistry* 1994; 109(1): 205-209.

Jasim K. Structure and electrical properties of lanthanum doped Bi_2Sr_2Ca_ {2-x} La_xCu_3O_ {10+\delta} superconductor. *Turkish Journal of Physics* 2012; 36(2): 245-251.

Wadia KM, Abdulateefa AN, Shabanb AH, Jasimb KA. Improvement of superconducting properties of Bi2Ba2Ca2Cu3O10+ δ Ceramic by prepared under different pressures. *Energy Procedia* 2019; 157: 222-227.